Expansion Governance Simulation for the Northern Seas Offshore Grid

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Overview

Development of the offshore grid is accelerating. European offshore wind site auctions saw significant price reductions, and multiple offshore interconnectors are in the construction or planning stage. Moreover, some multi-country offshore wind and transmission projects are in development, and the European Union is implementing a new climate and energy strategy, the Energy Union (Dedecca et al., 2017; European Commission, 2016).

An offshore grid has two functions: "the interconnection of onshore power systems through interconnectors, and the connection of offshore power generation technologies, usually wind power" (Dedecca et al., 2017). An integrated grid where transmission links combine both functions can provide greater net benefits to society than a non-integrated one. The offshore grid of the Northern Seas of Europe is the most concrete example of such a grid (Dedecca and Hakvoort, 2016).

However, the development of offshore grids is not necessarily towards integrated ones, and faces many barriers. A main one is the governance for planning and development of an integrated grid. It involves the complexity of multi-country cooperation, different preferences of the actors and countries involved, and the distribution of costs and benefits (Dedecca et al., 2017). These governance barriers were not modelled in existing quantitative research on the offshore grid (Dedecca and Hakvoort, 2016).

We study the governance barriers of the Northern Seas offshore grid, their impact on the expansion of offshore transmission and generation, and the distribution of costs and benefits. For this we develop an offshore expansion planning simulation model using myopic (shortsighted) optimization that is sequential and static. This myopic approach represents realistic investment decision making in offshore transmission and wind power by considering governance barriers, which leads to non-optimal and path-dependent expansions.

Our path-dependent simulation with more realistic investment decision modelling and different governance frameworks complements existing research on the Northern Seas offshore grid. The latter has applied either perfect-foresight optimization or qualitative models, without governance barriers (Dedecca and Hakvoort, 2016).

Methods

We improve the Offshore Grid Exploratory Model of Dedecca et al. (2017) by incorporating a more adequate technique for expansion candidate creation and management. We simulate sequential expansions of the offshore grid in 10-year periods, from 2030 to 2050, with offshore transmission and offshore wind power investments. We use a myopic mixed-integer linear optimization formulation by customizing the PyPSA package (Brown et al., 2016).

For implementing the governance constraints, we use the concept of integrated links, which are links from wind farms to foreign countries or to other wind farms. These links demand greater planning requirements than conventional interconnectors or wind farm connectors. With integrated links we model three novel constraints reflecting governance barriers: the Pareto welfare, the complex integration and the disintegrated planning constraint.

First, with the Pareto welfare constraint, the welfare of any country cooperating in an integrated offshore grid must increase, otherwise the country invests only in conventional links. Thus, the Pareto constraint represents the veto of Northern Seas countries to integrated links if they do not benefit from these. Second, with the complex integration constraint, only one new integrated link per offshore node is allowed in any expansion period. It thus represents the more difficult planning of integrated links. Third, with disintegrated planning no integrated links are allowed, representing the expansion of the offshore grid only with current, conventional links.

We use the clusterized network data from the e-Highway2050 project representing the European power system with 114 nodes (Sanchis et al., 2015). The base system operation is represented with a full year (8760 hours). We then select 100 representative hours using a k-medoids algorithm applied to nodal prices in order to perform the mixed-integer European system operation and offshore investment optimization.

Results

With or without governance constraints, all expansion pathways lead to a highly meshed network by 2050, combining some short AC links with especially point-to-point DC links. From 2030 to 2050 the network redundancy indicators of meshedness, node degree and node and link betweenness centrality all improve. For all cases, transmission investments amount to 18.5-20.5% of total investment costs, with countries paying for investments in their territory and cross-border links being split equally between the involved countries.

The unconstrained case results in a net benefit of B€20.7 per year compared to a case with no offshore investments, with a B€296.0 total investment cost (Table 1). Although net benefits are high, welfare is distributed unevenly among countries and actors – Norway and Sweden are the biggest losers. Hence the offshore grid has positive and negative

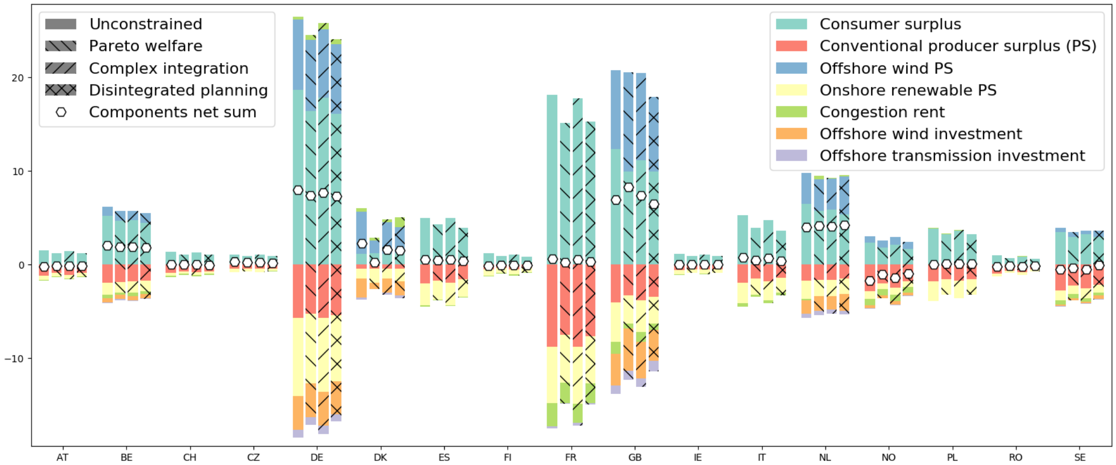

Figure 1: Welfare component changes for selected countries (B€/year)

externalities for neighboring countries. Generally, consumer surpluses increase, while congestion rents and producer surpluses decrease. Moreover, the welfare distribution can change significantly in sequential expansion periods.

We compare the addition of one governance constraint at a time. Welfare decreases up to -5.1%, which can represent a loss of B€1.1 p.a. to society, and changes in the distribution of costs and benefits can be greater (Figure 1). E.g., with constraints Denmarks's welfare can decrease by B€2.1 p.a. (89% from the unconstrained case), due to reductions in offshore wind surpluses. On the other hand, with the pareto constraint Norway may contain welfare reductions by up to B€0.7 p.a. by not cooperating in any integrated links, thus limiting the losses of its hydropower producers.

In the unconstrained and complex integration cases, few countries do not build integrated links, although the complex cooperation requires countries to focus on which links to build but does not impede cooperation altogether. With the Pareto welfare constraint only a few do, and in specific expansion periods. Thus, the Pareto welfare constraint is more restrictive to cooperation, leading also to the greatest welfare losses to society.

Regarding the transmission technology, the disintegrated planning constraint leads to the build-out of a HVDC grid in 2030 with more multiterminal than point-to-point links, which contributes to further path-dependent expansions, especially in 2050. Here, multiterminal links substitute point-to-point integrated ones in connecting Great-Britain to other countries, which then leads to multiterminal links also being used to connect British wind farms.

Table 1: Case indicators

		Welfare changes				2050 Offshore Grid				Technology		
Active governance constraint	Investment costs	Net benefits	Consumer surplus	Congestion rent	Producer surplus	Average link length	Average link capacity	Links per bus (beta index)	Maximum bus degree	HVAC	Multiterminal HVDC	Point-to-point HVDC
	B€$_{2030}$	(B€/year)				km	GW	-	-	TW.km		
Unconstrained	296.0	20.7	95.3	-5.8	-54.5	380.1	2.3	2.04	8	3.5	4.9	35.0
Pareto welfare	286.3	20.0	79.6	-3.8	-42.0	394.2	3.4	1.33	6	3.7	0.0	30.3
Complex integration	296.6	20.4	89.6	-4.6	-50.3	365.2	2.8	1.61	7	3.4	4.5	33.0
Disintegrated planning	294.9	19.7	77.3	-3.4	-40.0	400.8	2.9	1.64	7	4.6	22.7	15.3

Conclusions

Our novel path-dependent myopic deterministic model for offshore transmission and generation expansion improves the model of Dedecca et al. (2017) and asesses the impact of three governance constraints on the offshore grid. Previous qualitative studies of the Northern Seas offshore grid highlight governance barriers, and indeed despite the small share of transmission in total investment costs OGEM quantitatively demonstrates their significant impact on the grid wefare, its distribution, and the transmission technologies. The implementation of the novel governance constraints of OGEM in other transmission expansion models can support the planning of both offshore and onshore grids and advance energy systems governance.

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